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13. ABSTRACT (Maximum 200 Words) Three x-ray detector systems - storage phosphor, a prototype CCD, and a production model CCD were compared with respect to format, resolution, quantum efficiency, and systematics using synchrotron radiation in the range 15-40 keV. Overall, the CCDs performed faster than the storage phosphor and possessed higher quantum efficiencies. However, the storage phosphor had a superior spatial resolution (Modulation Transfer Function), and its larger format lends itself better to mammographic imaging than the smaller format CCDs. As a result of this comparison, criteria are being developed for selecting digital detection systems for the synchrotron-based diffraction enhanced imaging (DEI) system at the National Synchrotron Light Source, and for a clinical prototype for mammography using DEI.				
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Introduction

Three detector systems have been characterized to determine their relative strengths and weaknesses in recording x-ray images quantitatively. Recent developments in the new imaging modality, diffraction enhanced imaging (DEI) have led to the need for digital detectors to be integrated into the system [1 – 3]. In the quest to determine the ideal digital detector for the system, a comparison between three detectors has been conducted. This effort has revealed certain limitations and challenges relevant to acquiring images, and it has provided valuable training experience. Overcoming these limitations and challenges will be helpful to the mammography community in successfully diagnosing breast disease. This report will give a brief discussion on relevant detector characteristics, specifications on the detectors studied, and the subsequent results. Similar studies comparing detectors have been conducted in the past [4], but none with the express intent for evaluating them for integration into a mammographic research program. As a result of this study, new criteria are being developed for selecting digital detector systems for the synchrotron-based DEI system at the National Synchrotron Light source, and for a clinical prototype for DEI-based mammography. The systems studied are the Fuji BAS2500 Image Plate Reader, the MicroPhotonics XQUIS 1000, and a prototype CCD from Mar. The detectors were compared with respect to format, spatial resolution (Modulation Transfer Function (MTF)), quantum efficiency, and systematics using synchrotron radiation in the range of 15-40 keV. Attempts to measure the Detective Quantitative Efficiency (DQE) did not provide reliable results, and are not reported here. They will, however, be reported in a publication as improvements to the measurement are made. Also ongoing are attempts to obtain reliable data on dark noise and linearity in the detectors.

Annual Summary

Experimental Setup and Methods

Experiments were carried out at the X-15A beamline, a general-purpose beamline at the National Synchrotron Light Source, Brookhaven National Laboratory, Upton, New York. The apparatus setup is shown in Figure 1.

The apparatus consisted of a double crystal Bragg monochromator that prepared an imaging beam of 1-mm height and 8 cm width. For the experiments energies from 15 – 40 keV were used. The imaging beam was monitored by an ionization chamber to measure the skin entry dose to the various phantoms used to characterize the detectors. Plastic absorbers were used to control the dose to the phantom. A fast shutter system was used to control the exposure to the detector. The shutter opened when the scanning stage was at a constant velocity and was closed at the end of the scan range before the stage was slowed to a stop. The dose was controlled by a combination of incident beam Lucite absorbers and the scanning speed.

The MTF was measured by exposing an edge phantom to the imaging beam. The edge phantom consisted of an opaque material deposited (in our case Pb tape) deposited on a sheet of Lucite. The image was acquired and subsequently processed on computer.

The DQE was measured by exposing the image plate to incident radiation of various energies. Two ionization chambers measured the incident and transmitted signals and this data was recorded. Experimental determination of the DQE turned out to be more challenging than originally assumed. Analysis of the data revealed nonphysical results, which were quickly scrapped. However, data was collected for the Image Plate system, which provided reasonable

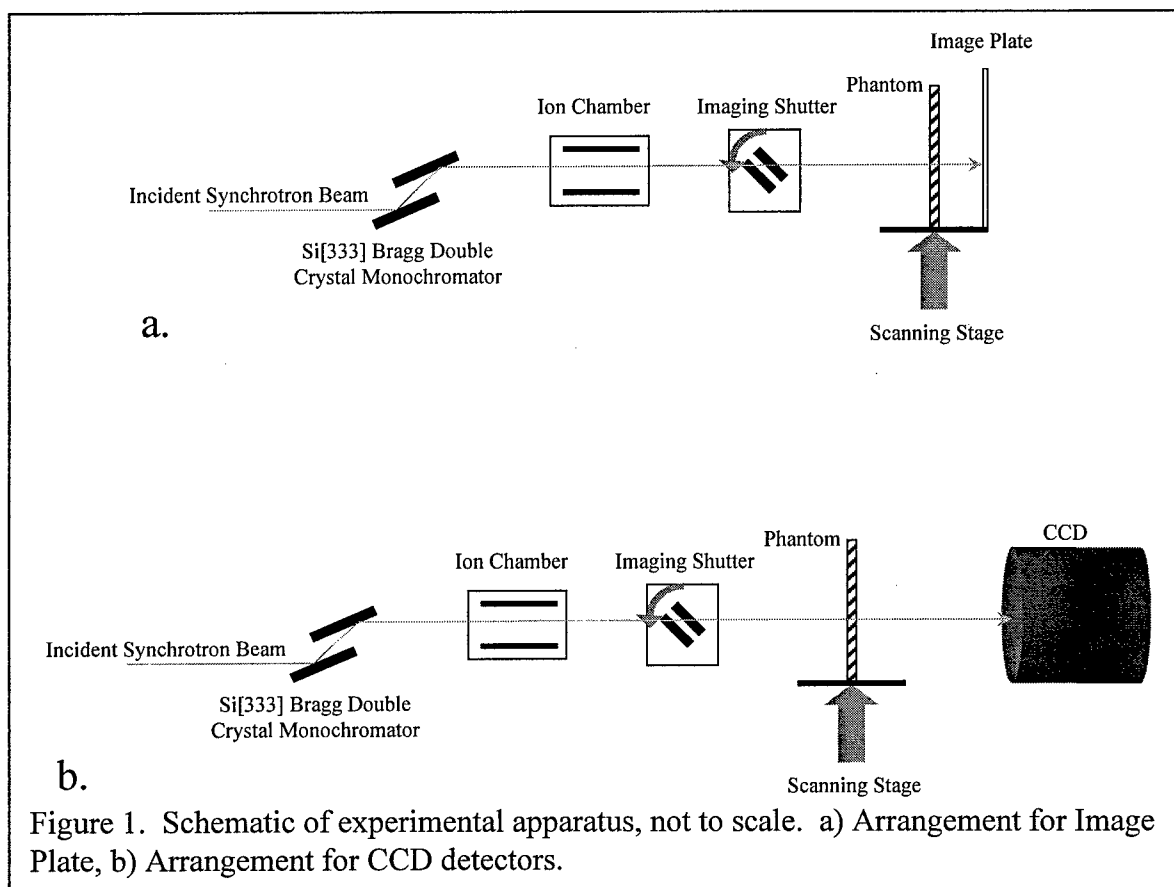


Figure 1. Schematic of experimental apparatus, not to scale. a) Arrangement for Image Plate, b) Arrangement for CCD detectors.

numbers. Direct measurement of the DQE is often difficult. Hasegawa suggests an approach, which is discussed in the following section [5].

Discussion of Results

Pixel Size: The MicroPhotonics CCD and the Fuji System both had pixel sizes of $50\ \mu\text{m}$, while the Mar CCD is listed as having a pixel of $64.396\ \mu\text{m}$. While these pixel sizes are relatively small, the system used in DEI experiments will require a smaller pixel in order to resolve features that are much smaller.

Pixel Format: The MicroPhotonics CCD has a 1024×1024 pixel format, and the Mar CCD boasts a 2048×2048 layout. The Fuji image plate is in excess of $200\text{mm} \times 250\text{mm}$, resulting in a pixel format of 5000×4000 . The Fuji system is clearly superior in this respect to imaging a full breast because it is well established technology for the size. Large format CCD's are still being developed. Two examples of the large format CCDs are given in [6, 7]. Another method is to use a strip detector, which can be built arbitrarily wide to accommodate large specimens but need only be a few pixels in height.

Readout time: Mar states that their CCD reads out an image in 3.5 seconds, while the MicroPhotonics claims that the XQUIS can read out a full image in 120 ms. The Fuji system is much slower, on the order of two minutes. This is compounded by the fact that the image plate had to be hand carried from the experimental hutch at the beamline to the image plate reader, which was located a few meters away. Newer CCDs will have faster readout times so improving on these values for the future should not be difficult.

MTF: Processing the data for the MTF also comes from [5] and is summarized here. In characterizing the spatial resolution of a detector, it is often desirable to determine the Point Spread Function, which is the image of an ideal point object projected onto a detector. This is difficult to measure experimentally, but an indirect method via the MTF is more convenient. In this study an opaque edge was imaged. The MTF can be expressed as

$$\text{MTF}(u, v) = |\mathfrak{F}[\text{PSF}(x, y)]|, \quad (1)$$

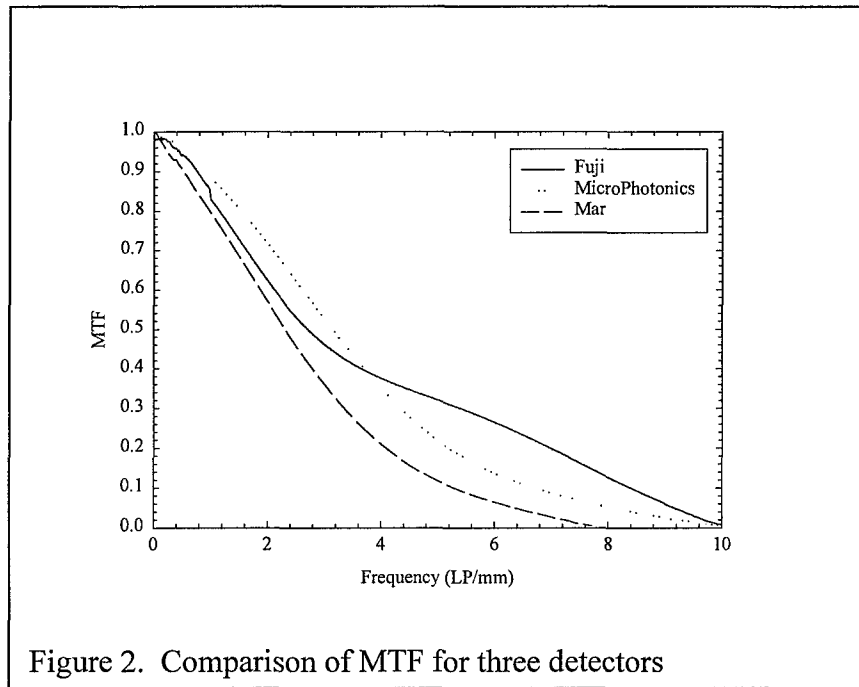
or in simple terms, the MTF is the norm of the Fourier Transform of the Point Spread Function (PSF). Then by integrating the PSF in one direction we can obtain a 1-D representation, called the Line Spread Function (LSF). Mathematically, this obtained by

$$\text{LSF}(x) = \int_{-\infty}^{\infty} \text{PSF}(x, y) dy. \quad (2)$$

As it turns out, the LSF is the first derivative of the Edge Spread Function (ESF), or

$$\text{LSF}(x) = \frac{d}{dx} \text{ESF}(x), \quad (3)$$

where the ESF is the response by the detector to an opaque edge. Thus, the MTF can be determined. The comparison of MTF's is shown in Figure 2. All three detectors have similar performance at low spatial frequencies, but then deviate around 4 LP/mm. As the spatial frequency increases, the image plate system had the best performance. The Mar CCD has no response above 8 LP/mm since its pixel size is bigger than the other two detectors and it has reached its maximum resolution there. In fact, its overall poorer performance is largely due to the fact that it is much older than the other two detectors and is a prototype.



DQE: Results for the energy-dependent DQE are shown for the Fuji system in Figure 3. It is clear from the results that the DQE is approximately 60% and is only weakly dependent on the incident radiation. Determination for the two CCDs are ongoing and are not presented here. It is expected that the values for the CCDs will be higher than that of the image plate.

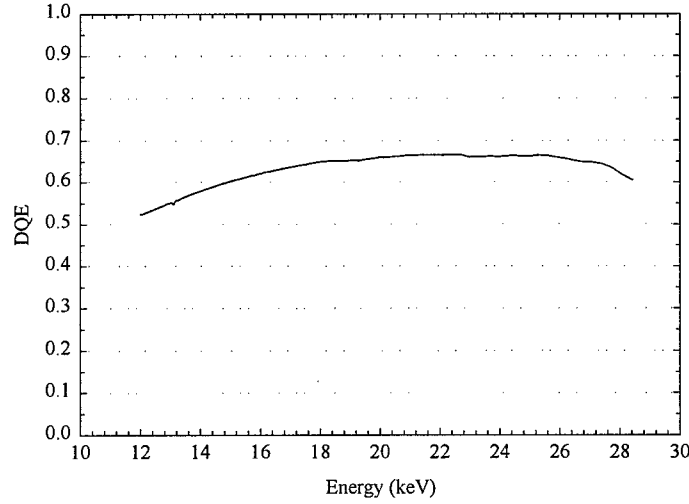


Figure 3. DQE spectrum for the Fuji system

The DQE is a comparison between the signal-to-noise ratio (SNR) of incident radiation on the detector and the SNR of the data generated in the detector. Mathematically, it is expressed as:

$$DQE = \left(\frac{SNR_{out}}{SNR_{in}} \right)^2. \quad (4)$$

If the detector has a certain thickness, t and an attenuation coefficient μ , then the number of photons transmitted through the detector is given by

$$N_t = N_0 e^{-\mu t}, \quad (5)$$

where N_0 is the number of incident photons on the detector. The difference between the two numbers is then the number of photons absorbed by the detector and therefore used in generating the data signal. This is expressed as,

$$N_a = N_0 (1 - e^{-\mu t}). \quad (6)$$

If the number of incident photons on a detector is affected only by Poisson noise then

$$SNR_{in} = \frac{N_0}{\sqrt{N_0}} = \sqrt{N_0}. \quad (7)$$

Likewise, the detector is only subject to Poisson noise, then

$$SNR_{out} = \frac{N_0 (1 - e^{-\mu t})}{\sqrt{N_0 (1 - e^{-\mu t})}} = \sqrt{N_0 (1 - e^{-\mu t})}. \quad (8)$$

Then the DQE is expressed as,

$$DQE = 1 - e^{-\mu t}. \quad (9)$$

Training Accomplishments

As a result of the efforts of the past year, a great deal of training value has been gained. Expertise in the operation of a synchrotron beamline has been achieved. This is important for future endeavors, especially as personnel availability in the DEI collaboration will inevitably change. Processing the data and images from this study has resulted in gained expertise in image processing techniques. This expertise and experience has also been supplemented by formal coursework in digital imaging. The experience has also prompted investigations into the next stage, namely the development and implementation of image processing techniques. Finally, an overall knowledge of digital detectors has proved to be an excellent foundation for other members of the DEI collaboration

Key Research Accomplishments

- Measured the MTF for the three detectors and showed that the Fuji system has the best spatial frequency resolution
- Showed that the CCDs are superior in readout times and convenience of use
- Conducted calculations on the quantum efficiency of the detectors (despite the need to re-do this, it is expected that the CCDs will possess higher quantum efficiency than the Fuji system)
- Identified key criteria for selecting detectors for both the synchrotron-based DEI research system as well as for the clinical prototype.

Reportable Outcomes

- A poster on this topic was given at the 11th National Synchrotron Radiation Instrumentation Conference, October 13-15, 1999, Stanford, CA
- It is intended that the results of this work will be submitted for publication before the end of the calendar year

Conclusions

This study has provided useful information into the characterization of digital detectors for integration into both a synchrotron-based mammographic research program, as well as the development of clinical prototype DEI-based mammography.

From the study it is clear that the CCDs are technologically superior to the Image Plate in that the image can be acquired much more quickly and be processed with more ease. The Fuji system performed very well and is a reliable detector. One of its best qualities is its active area, (more than $200 \times 250 \text{ mm}^2$). This is a far larger active area than in either CCD. Its image quality compares well with the CCD, and continues to be the detector of choice for the DEI collaboration, mostly due to the fact that it belongs to the collaboration and the other two detectors were borrowed for the study. The Fuji system also exhibited a superior MTF most likely due to it being optimized for medical applications and because it is newer technology than the other two detectors.

Integration of a digital detector will require the study and characterization of additional detectors. Indeed, the DEI collaboration is in the process of requesting funding for the purchase of such detectors as well as developing a clinical prototype mammography device. Included in this future effort will be the modeling of imaging characteristics of typical cancerous effects in the breast. These effects, such as clusters of microcalcifications and spiculations, provide unique challenges to the detectors acquiring the images. By modeling the imaging characteristics and

conducting subsequent imaging experiments, the capabilities and requirements of the detector can be fully optimized.

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